Non-relativistic and relativistic quantum kinetic equations in nuclear physics.

Botermans, Wilhelmus Martinus Maria

CHAPTER V EPILOGUE

In this thesis, we discussed the derivation of quantum kinetic equations appropriate for applications in nuclear physics, both in a non-relativistic and in a relativistic context. In each case we obtained a kinetic equation together with an equation for the effective interaction. The latter serves as the dynamical input of the former. In the kinetic equation both mean-field and collision effects are described in a self-consistent way because both are expressed in terms of the effective interaction. This *self-consistency* enforces us to solve a statistical problem (kinetic equation) and a dynamical problem (effective interaction) simultaneously. The interaction, that we obtained as a result of our considerations, is a generalized version of the usual Brueckner G-matrix in the sense that single-particle energies are corrected for collision effects by the so called *rearrangement-term*. Only in this way kinetic theory and interaction are consistent with one another and therefore constitute a conserving approximation.

To acquire the complete numerical solution of this problem will be a very difficult task (if possible at all). In practice one usually recurs to simulations of the collision process. Up to now this has been done by invoking the *quasi-particle approximation* as well as the semi-classical limit. However from our considerations in chapter 3 it will be clear that above 100 MeV/nucleon this approximation is no longer valid because the imaginary part of the self energy is non-negligible in this energy domain. It would be of great interest to account for this fact in the simulations and investigate to what extend it affects the collision dynamics.

Another interesting new feature to investigate with these simulations is the *spin dependence* of the collision process. Since the nucleon-nucleon interaction itself is strongly spin dependent we might expect that the same is true for the colliding nucleus-nucleus system. In the relativistic case we explicitly treated the spin degrees of freedom in the derivation of the kinetic equation. As a result we obtained a (2x2) matrix equation in spin space in which the drift term preserves its usual form but where in the collision term both the gain and the loss contribution consists out of two terms only differing in their spin structure. We remark that the spin structure of the kinetic equation would be equivalent in the non-relativistic case.

Next, we discussed the relativistic kinetic equation in more detail. A most satisfying feature of it is the proper inclusion of the correct dynamics, i.e. the one given by the *Dirac-Brueckner appraoch* including the rearrangement term. Recently[102], it became clear that the relativistic interaction, as compared to the non-relativistic one, has a complete different density dependence due to the use of effective spinors. This alteration provided an additional saturation mechanism, and resulted in a better description of nuclear matter properties in equilibrium. It was one of the main objectives of the last chapter to include this interaction in a kinetic theory. In the resulting relativistic kinetic equation the Lorentz components of the self-energy appear (via the single-particle energy). Under Lorentz transformations these components transform in a different way. This genuine relativistic fact might have significant consequences in heavy-ion collisions at higher bombarding energies.

Despite these satisfying features the kinetic equation suffers from a number of shortcommings. First of all, at higher energies the explicit manifestation of mesons, delta's, kaon's, etc. should be accounted for. This should be done by including these particles in the Lagrangian[148] and following a similar procedure as was done here. Other omissions of the relativistic kinetic theory formulated in this thesis are the inclusion of negative energy states, formfactors and polarisation contributions in the interaction. However these questions should in the first place be considered in an equilibrium theory before it makes any sense to construct the non-equilibrium version of it.

In this thesis, we concentrated on the formal derivation of quantum kinetic equations. This is the first step in the exploration of the difficult nuclear collision theory. The next step, of course, is to check the validity of the approximations invoked. This should be done by explicit calculation. However, the calculations (simulations) made thus far, do not take into account any of the points that we mentioned above viz. the self-consistency, the limited validity of the quasi-particle approximation, the spin dependence and the Dirac-Brueckner effective interaction including the rearrangement term. Once these calculations are performed, they hopefully will show in what respect we should modify the approximations in the formal theory. Only in this way, the formal and numerical approaches shall benefit from one another and may in the end yield a synthesized picture of the nuclear dynamics involved.